3.2.5 Heating equipment

Input data concerning the existing heating system are:

- Type of equipment
- The thermal power of the equipment
- The efficiency
- The remaining life

Several types of equipment can be dealt with by the model. The alternatives are, with the abbreviations for the OPERA recognition and for the code:

Oil-boiler	OIL-BOILER
Electricity, fixed rate	ELFIX
District heating, fixed rate	DISFIX
Heat pump, ground water coupled	HPGROUND
Natural gas	NATGAS
District heating, differential rate	DISDIFF
Electricity, differential rate	ELDIFF
Bivalent oil-boiler - heat pump, ground w.	
Bivalent oil-boiler - heat pump, outside air	

The first eight systems can be considered as existing heating systems. The other two have not been implemented because they are not in common use in the existing building stock, but the program, of course, considers them as plausible retrofits. The input text, e.g. ELDIFF, must be identical to the ones stored in OPERA, otherwise the model cannot recognize the system.

The first value is used for comparing the existing power installed, with the calculated need, provided by the OPERA model. OPERA tells the user if the system is too big or too small according to ordinary design routines, common in Sweden. The model uses the calculated power in continuing calculations.

The efficiency of the heating system is given as less, equal or higher than 1.0. The efficiency for ordinary oil-boilers is approximately 0.7 while heat pump systems can have "efficiencies", or Coefficients Of Performances, COP, of the magnitude 3. There are of course, difficulties in choosing the values, because no absolute accuracy can be given. In [1] some of the problems are discussed and references are given mostly to Swedish literature.

Also here, in the heating equipment case, it is important to consider the remaining life of the existing system. There are difficulties to provide an accurate value, but nevertheless a qualified guess must be made.

The values found in line 8 in the input data file are:

Type of existing equipment	'OIL-BOILER'	VATYP
Existing thermal power	110 kW	EF
Efficiency	0.75	VGVAR
Remaining life	5 years	LVA

Note the quotation marks around the text input. The number of characters is limitid to 30.

3.2.6 Domestic hot water use

OPERA also has to consider the hot water consumption in the building and the model requires information about the annual consumption in kWh. The calculations are made, assuming that no extra power is needed for this, because of the short duration of the top peak load during the coldest winter days. However, this is not the fact for the bivalent system calculations. See [1] for more details.

The value used in the example is 42 000 kWh/year and the variable name is TV.

3.2.7 Thermal properties of new envelope measures

The model has to be informed of the new thermal conductivities in the insulation material. Values have to be provided for the attic floor, the floor and the external wall insulation. These values must correspond to the building cost functions below.

The thermal performance of different types of windows are presented as U-values during darkness. The values must correspond to the cost functions for the windows.

The figures presented in the next lines in the data file are:

New thermal conductivity, attic floor	0.04	W/m·K	NLAT
floor	0.05		NLAG
external wall, out.	0.04		NLAY
external wall, ins.	0.05		NLAI
New U-value triple-glazed windows	2.0	$W/m^2 \cdot K$	MK3
low-emissivity, triple-g	1.5		MK4
low-emissivity, gas, triple-g.	1.2		MK5

Note that the type of windows is unimportant to OPERA, but the U-value is important and the building cost for changing windows presented below. It has been found that the thermally best type of windows are rarely chosen by OPERA. If nevertheless such windows are selected the program terminates. The way of solving this is to replace the MK4 value with the MK5 value and the corresponding building costs below in the input data file.

3.2.8 New life-cycles for the envelope retrofits

The retrofits on the envelope will change the periodicity when the retrofits are inevitable. The new life span in years must thus be provided for the attic floor, the floor, the external wall and the windows. The situation is discussed in detail in [1].

The values in Figure 3 are:

New life-cycle, attic floor	50	years	NLT
floor	50		NLG
external wall, out.	50		NLY
external wall, ins.	50		NLI
windows	30		NLF

3.2.9 Economical factors

One of the most important values in the LCC calculations is the discount rate. The item is discussed in e.g. [1], [12] and [13] where more information can be found. The discussion can be summed up just by saying that there is no ultimate discount rate, but the references advise us to use a rate between 4 and 11 %. The rate used in OPERA is the real discount rate, i.e. inflation excluded. A recent paper shows that a rate between - 0.2 and 4.0 % has been used in the reallity for high quality dept instruments such as domestic corporate utility bonds, [14].

Neither can an ultimate optimization time or project life be found. In Sweden there are special subsidies for buildings older than 30 years or if more than 30 years have passed since it was last renovated with subsidies. In this case there must be a qualified guess to provide the model with a suitable value.

This is also the case for future escalating, or falling, energy prices. OPERA requires a value for the annual increase in % or zero. The problem is also dealt with in [1]. The influence from escalating energy prices is calculated in OPERA with the help of a justified discount rate. The expression is:

$$r_j = \frac{r - q}{1 + q} \qquad (3)$$

where r_j equals the justified rate and
q the annual increase in energy prices.

Note that expression (3) yields an approximate value. If q equals r the rate will be 0 and if q is greater than r the justified rate will be negative. Negative values will work fine but if the result is 0 or close to it a proper value is set in the code, see appendix A. If q and r are equal the present value factor will equal the project life of the building. It must also be remembered that running the program until it automatically terminates, will yield calculations for a number of different annual energy price escalations. The values used in the example are found in line 15 in Figure 3. They are:

The project life	50 years	OPTA
The real discount rate	0.05	R
The annual escalation	0.00	Q

3.2.10 Building cost functions

OPERA must be given the building costs for different retrofit measures. As mentioned earlier, there is also a need for the inevitable retrofit cost if related to energy conservation measures. First, OPERA must calculate the present value for e.g. an external wall, without any energy retrofits. Sooner or later, the facade has to be renovated, e.g. because it is affected by rot. Earlier in the input data file, this instant is specified and the cost function will tell OPERA the expense.

However, the cost function must also provide the model with the specific insulation cost.

In [2] and in [15] it is shown that an expression for the building cost can be written as:

$$C_1 + (C_2 + C_3 \cdot t_{in}) \qquad (4)$$

where C_1, C_2 and C_3 are different constants and
t equals the extra insulation thickness.

C_1 shows the value for the inevitable cost while C_2 and C_3 are connected to the direct insulation cost. In [15] the example enlightens the elaboration of the three constants, see Table 1.

Table 1. Building costs for retrofitting an external wall with extra insulation. Prices in SEK/m^2 [15].

	Price
Scaffolding	29.70
Demolition of boarding	8.70
New boarding	104.40
Mineral wool of thickness t	6.96 + 230 · t
New studs	19.72 + 260 · t
Indirect costs, non-insulation	144.87
Indirect costs, insulation	48.29
Taxation for non-insulation	37.02
Taxation for insulation	9.64 + 63.06 · t
Sum of non-insulation costs	324.69
Sum of insulation costs	84.61 + 553.06 · t

In Table 1 the direct insulation costs are separated from the costs not coupled to the insulation material. Figure 4 gives a graphic presentation. The inevitable retrofit cost only consists of the non-insulation cost, C_1, i.e. 324.69 SEK/m^2. When extra insulation is added the cost will increase with (84.61 + 553.06 · t) SEK/m^2, $C_2 + C_3 \cdot t$. The C_1- value is thus coupled to the remaining life for the building asset and to the new life for the same asset, while the C_2 and C_3 values are coupled only if the asset is extra insulated.

Figure 5 gives a graphic representation.

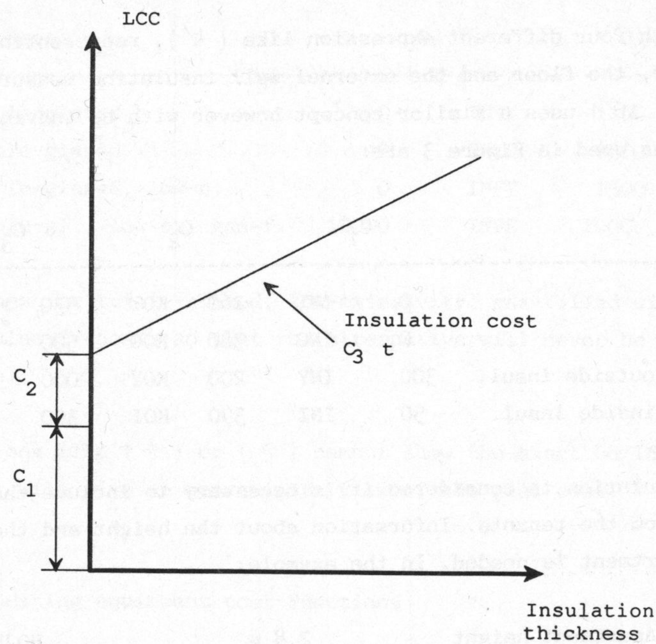

Figure 4. The retrofit cost for insulation measures

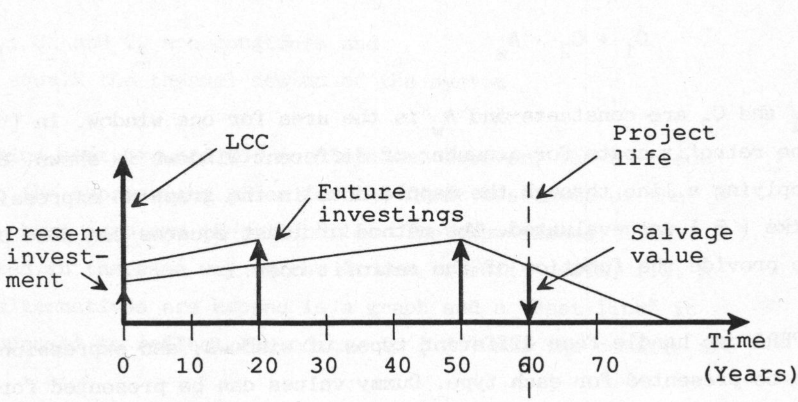

Figure 5. The present value calculation

OPERA deals with four different expression like (4), representing the attic floor, the floor and the external wall insulation measures. The author of [16] uses a similar concept however with no inevitable cost. The values used in Figure 3 are:

Asset	C_1		C_2		C_3	
Attic floor	0	INT	260	KOT	530	AKT
Floor	0	ING	380	KOG	500	AKG
External wall outside insul.	300	INY	200	KOY	2000	AKY
External wall inside insul.	50	INI	390	KOI	300	AKI

When inside insulation is considered it is necessary to include the loss of rent from the tenants. Information about the height and the rent of the apartment is needed. In the example:

Apartment height	2.8 m	HOJD
Apartment rent	450 SEK/m^2 · year	HYRA

The retrofit cost for the windows is described with only two constants as can be found in the following expression:

$$C_1 + C_2 \cdot A_w \qquad (5)$$

C_1 and C_2 are constants and A_w is the area for one window. In [2] the retrofit costs for a number of different windows is shown. By applying a line through the mapped dots in the graph an expression like (5) was evaluated. The method of least squares can also be used to provide the function of the retrofit cost.

OPERA can handle four different types of windows, and expressions have to be presented for each type. Dummy values can be presented for OPERA, if only a few alternatives shall be considered. The procedure is described in detail in [2]. The values used in the example are:

Asset	C_1		C_2	
Double-glazed	0	INTV	1100	AKTV
Triple-glazed	0	INTR	1300	AKTR
Triple-glased, low-e.	0	INFY	1500	AKFY
Triple-gl., low-e., gas-f.	10000	INFE	10000	AKFE

The values for triple-glazed, low-emissivity, gas-filled windows are dummy values, chosen so that the alternative will never be selected by the model.

Expressions like (4) or (5) cannot show the exact building cost, but they will give an approximate view of the real cost.

3.2.11 Heating equipment cost functions

The cost for acquisition and installation of new heating facilities must also be known to OPERA, e.g. by using expressions like:

$$C_1 + C_2 \cdot P + C_3 \cdot P \qquad (6)$$

Where C_1, C_2 and C_3 are constants and
P equals the thermal demand of the system.

One expression must be used for each system. However, the bivalent systems use the expressions given for the first heat pump or the outside air heat pump and the oil-boiler. The expressions, like (6), are evaluated in the same way as the window retrofit costs, i.e. a number of alternatives are mapped in a graph and a "best line" is applied, supposed to reflect the costs. In [2] all the details are shown.

Naturally the efficiency, COP, and the new life span, L_1, for the equipment must also be presented.

The program can also deal with installations like chimneys for oil-boilers or drilling holes for ground water coupled heat pumps, namely the cost C_3. All these items have a much longer life-cycle, L_2, than the precise heating facility itself, why they have to be treated separately. A chimney can have a life span of 50 years, while the oil-boiler has a life-cycle of 15 years.

The input data found in the lines 24 - 29 are the following:

Asset	C_1	C_2	COP	L_1	C_3	L_2
Oil-boiler	55000	60	0.75	15	200	50
Electricity boiler	20000	100	0.95	25	1	50
District heating	40000	60	0.95	25	300	50
Ground w. heat pump	60000	5000	2.5	50	1500	10
Natural gas boiler	55000	50	0.8	20	200	50
Outside air heat p.	60000	6000	see below	15	200	40

The corresponding variable names found in the code are:

Oil-boiler	INPO	AKPO	VGVNO	NLPO	SLANGO	LSLANGO
Electricity boiler	INPE	AKPE	VGVNE	NLPE	SLANGE	LSLANGE
District heating	INPF	AKPF	VGVNF	NLPF	SLANGF	LSLANGF
Ground w. heat pump	INPV	AKPV	VGVNP	NLPV	SLANGV	LSLANGV
Natural gas boiler	INPY	AKPY	VGVNY	NLPY	SLANGY	LSLANGY
Outside air heat p.	INPU	AKPU	VGVNU	NLPU	SLANGU	LSLANGU

When the outside air heat pump is considered the COP of the pump cannot be reflected with only one constant, as the COP varies due to the outside temperature. In [1] an expression shows this influence:

$$COP = \frac{-\Delta T + 66.43}{20.53} \qquad (7)$$

The two constants can be found in Figure 3, and in the code they are named UTE1 and UTE2 respectively. Δ T shows the difference between the inside and outside temperature.

There are however, also other differences. The outside air heat pump is supposed to be renovated after some years. The cost for this is assumed to be reflected in a certain percentage of the total installation cost. In the input data file this share, named PROC, is 0.1 and the renovation appears every 7 years, named LPROC. In [17] LCC and different types of heating equipment are discussed.

3.2.12 Climate conditions

In the OPERA model the climate conditions are described by monthly mean values of the outside temperature in °C. Three different climates can be put into the data file. OPERA picks the applicable one after reading a variable in the file, named ORT. If ORT equals 1 the first line is chosen and if ORT equals 2 the next one and so on. The values, showing the temperatures, are put into an array KLIM(3,12) and the figures in the example show the climates in Malmö, Linköping and Kiruna, Sweden. The values are:

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Malmö	-.5	-0.7	1.4	6.0	11.0	15.0	17.2	16.7	13.5	8.9	4.9	2.0
Linkö.	-2.9	-3.0	-0.1	5.3	11.0	15.4	17.7	16.4	12.2	7.1	2.7	0.0
Kirun.	-12.2	-12.4	-8.9	-3.5	2.7	9.2	12.9	10.5	5.1	-1.5	-6.8	-10.1

Note that the designing outside temperature is set below.

3.2.13 Costs for ventilation measures

Weatherstripping will be profitable in most of the OPERA runnings. The program assumes that the cost can be predicted by showing the cost for caulking one window or door and furthermore, the number of doors etc. to be dealt with. Important is also to present the decrease in the ventilation flow after weatherstripping is completed, [18]. The life span of the caulking measures must be known to the model.

Exhaust air heat pumps are dealt with by presenting the cost for the heat pump due to its thermal power. The expression is similar to (6).

The temperature of the in- and outflowing air must be given, and OPERA will calculate the proper thermal power of the heat pump and proceed with the heat pump cost, the life-cycle of the pump and its COP. Similar to oil-boilers and chimneys, the heat pump needs installations with another life-cycle then the pump itself. Those costs are presented due to the number of apartments in the building and the life span of the installations.

In Sweden the power of the heating equipment is designed due to the Lowest Outside Temperature. This temperature can be found in the Swedish building code and in Malmö it is set to - 14 °C or -16 °C due to the type of building. Heavy building material corresponds to the higher of the temperatures. This method makes it possible to take into account the influence of the thermal mass in the building. The problem is discussed more in detail in [2].

The values, found in Figure 3 are:

Number of items to seal	56	Pcs	AOP
Cost for sealing one item	250	SEK	KPO
Decrease in ventilation flow	0.1	Ren./hour	OMDIFF
New life for weatherstripping	10	Years	LITA
Number of apartments	14	Pcs	ALGH
Inlet temp. in exh. air heat pump	20	°C	TFIN
Desired inside room temperature	21	°C	TIN
Designing outside temperature	-14	°C	DUT1
Cost for piping, exh. air hp.	10000	SEK/apart.	ROR
New life of this piping	50	Years	LROR
Exh. air heat pump cost, C_1	10000	SEK	INFL
Exh. air heat pump cost, C_2	4500	SEK/kW	AKFL
New life of the heat pump	10	Years	LFL
COP of the heat pump	2.0		VGFLVP
Outlet temperature, exh. air hp.	10	°C	TFUT

Note that the number of items and the number of apartments above are integers.

3.2.14 Project name, site and output parameters

In the next line of the input data file it is possible to write the project name, in this case UPPLAND 5. The name must be shorter than 30 characters, note the quotation marks in Figure 3. The variable in the code is OBJECT.

The next value shows OPERA which site is of concern. The variable is called ORT and the number for it selects the applicable climate. The value can be 1, 2 or 3.

In the input file values for the output presentation of OPERA can be asssigned. Part of the calculations can be presented at the terminal or on the line printer etc. This means that it is possible to scrutinize each step of the calculations. Further by small changes in the code part of the calculations, e g one of the subroutines or the exhaust air heat pump, can be considered in detail.

By assigning other values to the programming loops it is possible to control how many cases of discount rates etc that shall be presented by the model. This provides the operator with a very good means for sensitivity analysis, i.e. how much the optimal solution changes if the input data are changed.

There are eight different parameters, all of them integers. If a parameter equals 1 the output is written on the screen, if it equals 0 it is written to a dummy file, called NUL by DOS, and if it equals 3 it is written on the printer. See the OPEN statements in the FORTRAN code, appendix A. The variables are:

Outputs	Value in Fig. 3	Variable name
Basic result	1	U
Insulation optimization	0	U1
Detailes from main program	0	U2
Bivalent optimization	0	U3
Diff. rates, district heat.	0	UT7
Diff. rates, electricity	0	UT8
Miscellaneous	0	UT10
Input data	1	U11

Note however, that using the extra information mostly demands expert knowledge of the program code. It is not meant for the novice users of the model.

There is also one parameter for terminating the program after the base case has been studied. This parameter an integer is named ST1. If another value than 1 is set, the program continues as usual.

3.2.15 Solar gains and free heat from appliances and persons

The values for solar gains, stored in an array called SOL(4,12), and free heat, stored in an array called GRATIS(12), must be given to OPERA as monthly mean values in the input data file. The solar gains are assumed to be presented as the heat in kWh/m^2, transferred through a double glazed window for the considered orientation. Four orientations can be dealt with without extra programming work. Note that the values must correspond to the other data concerning the windows above. These values can be calculated using the SORAD program shipped with OPERA, see chapter 6.

Also necessary to provide are the shading coefficients concerning the types of windows, stored in an array called SHADE(3). The values show how much of the solar radiation lost, when a window with a better thermal performance is introduced. The values shown in the example are:

Free gains from appliances and persons 4167 kWh/month GRATIS

There are 12 values, one for each month, but in this example they are all identical.

The solar gains presented in the example are:

Month	North	East	South	West
January	4.3	8.27	29.66	8.27
February	8.94	17.97	43.69	17.97
March	18.57	41.86	69.73	41.86
April	28.82	61.97	75.29	61.97
May	44.50	87.58	82.59	87.58
June	53.48	90.91	76.28	90.91
July	50.54	89.07	78.50	89.07
August	36.63	75.07	79.81	75.07
September	23.12	53.11	79.37	53.11
October	13.54	28.30	61.57	28.30
November	5.82	10.75	32.70	10.75
December	3.08	5.36	21.22	5.36

The shading coefficients shown in the input data file are:

Triple-glazed	0.1
Triple-glazed, low-emissivity	0.2
Triple-glazed, low-emissivity, gas-filled	0.3

Note that the coefficient shows the sun shade compared to a ordinary double-glazed window. If triple-glazed windows are introduced 10 % less sun is transferred through the window panes. If very high shading coefficients are used it might give strange results. The problem is dealt with in [19]. It is thus recommended to use shading factors lower than 0.5.

3.2.16 Energy prices and rates

Information about the energy cost is essential for the result of an OPERA running. For the oil-boiler or the electricity case the energy cost must be presented, as a price in SEK/kWh, while for district heating and natural gas, information also is needed about the connection fee. The heat pump cases use the electricity price, and if applicable the, oil price.

Also implemented in this example are real tariffs for energy used by the utilities in Malmö, i e the differential rates. The tariff elements are stored in the input file and new values can easily be implemented. If a completely new tariff, with a different design, will be used it is necessary to make small changings in the FORTRAN code, see the subroutine TAXOR in the code, appendix B. The design of the tariffs is dealt with in [1] and thus only a brief presentation is given here.

3.2.16.1 Prices for oil,electricity and natural gas, fixed rates

The first three lines dealing with the energy prices shows:

Price of oil	0.233	SEK/kWh	EOL
Price of electricity	0.3658357	SEK/kWh	EEL
Price for natural gas	0.175	SEK/kWh	EGAS
Connection fee, natural gas	120	SEK/kW	ANSGAS

It might seem peculiar to use seven decimals in the electricity price, but is because OPERA also calculates the optimal retrofit strategy when differential rates are considered. If the design of the rates are to be examined, it is important that a fixed rate, with a static price for electricity over the year and time of day, can be compared to a differential one, where the price varies with the time of use. The level of the two rates must then be identical which means that they are normalized. OPERA calculates this normalized price during execution of the subroutine TAXOR. If another building is considered, i.e. the load changes, this will lead to a new normalized fixed price. See [20] for a more detailed discussion about normalization of rates.

3.2.16.2 District heating rates

The same discussion is applicable also when district heating is considered. First a fixed price is presented in the data file, and then some values which present the real rate.

Energy price fixed rate	0.2763422	SEK/kWh	EFJ
Connection fee	300	SEK/kW	ANSL
Fixed fee, D <= 800 kW,	700	SEK/Year	FAST
Fixed fee, D > 800 kW	2400	SEK/Year	FAST
Power fee,	600	SEK/kW·Year	FAST
Reduction factor	0.64		RV

The value for D above is calculated as the energy demand during January and February, divided by the number of hours during that period. The connection fee is multiplied with the maximum load during one hour, while the power fee is multiplied by the value D above. The reduction factor is multiplied with the power fee which makes the fee lower in this case. The variable FAST above, is an array with three elements.

The energy prices differs due to the season and they are:

November - March	0.195	SEK/kWh	EP
April - October	0.145	SEK/kWh	EP

EP is an array with 12 elements